Flight Experiment Platforms/Opportunities

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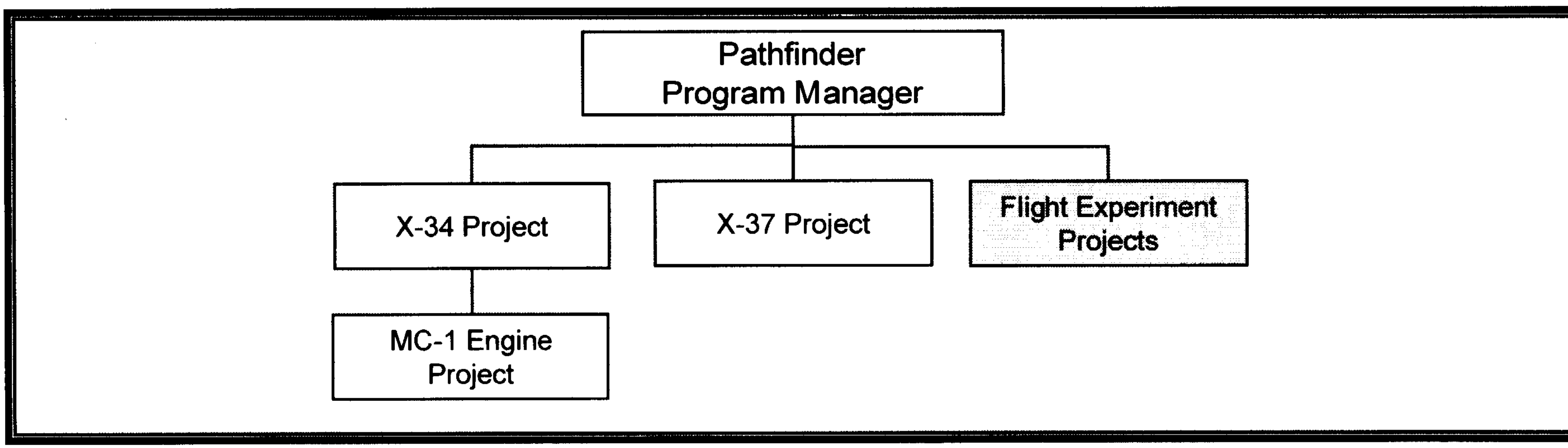
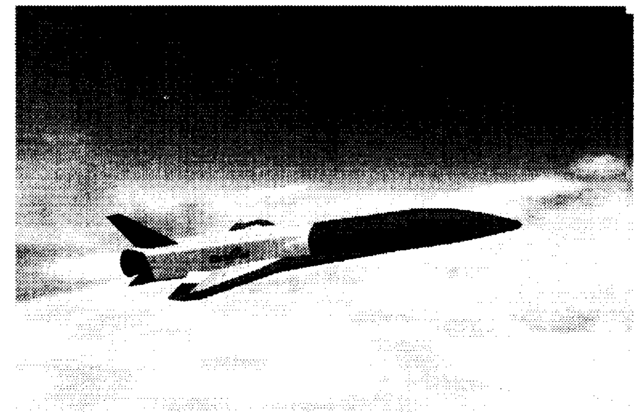
Pathfinder Experiments Project Office

- FLY EXPERIMENTS ON ANY VEHICLE AVAILABLE
- GROUND TEST EXPERIMENTS AT AVAILABLE LOCATIONS EWS

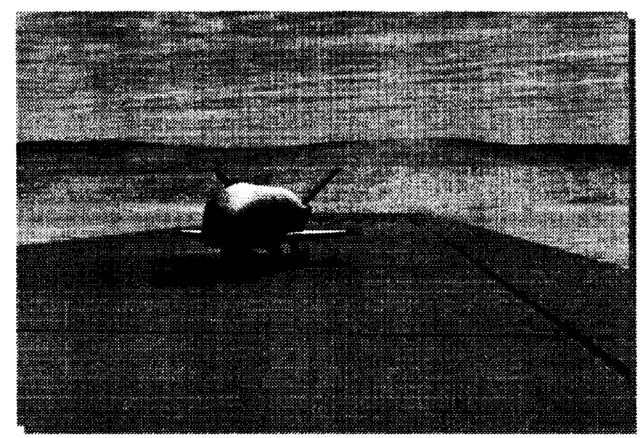


Pathfinders X-34 and X-37 Projects

- **X-34 Rocket Plane is a Suborbital/Atmospheric Technology Testbed**
  - Modular Design
  - Embedded and Hosted Technologies and Experiments
  - Low Cost Operations Testbed



- **X-37 Space Plane is an Orbital/Reentry Technology Testbed**
  - First Orbital Test Bed X-vehicle
  - Modular Design
  - Embedded and Hosted Technologies and Experiments



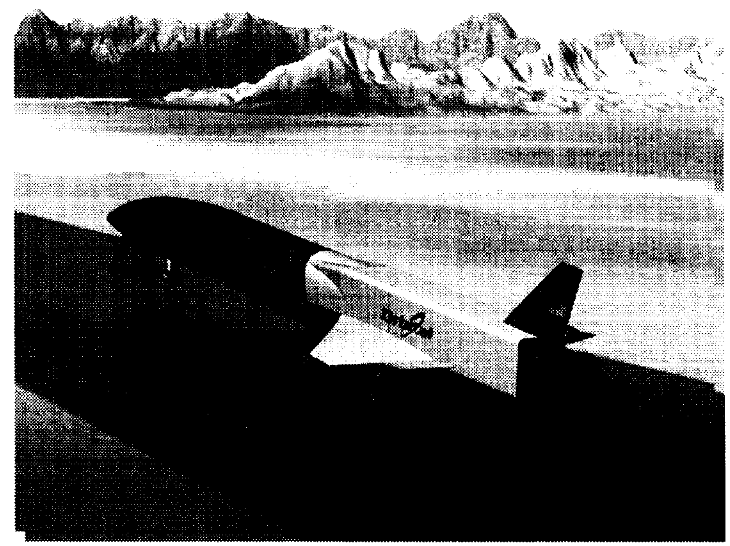
X-34 Focus Area Technical Goals

New RLV Technologies Embedded in Vehicle Design

- **Demonstrate technologies throughout flight profile**
  - Subsonic and hypersonic flight
  - Capable of powered flight to at least 250k ft
  - Capable of attaining Mach 8
- **Capable of autonomous flight operations**

Investigation of New Methods for Low-Cost Operations

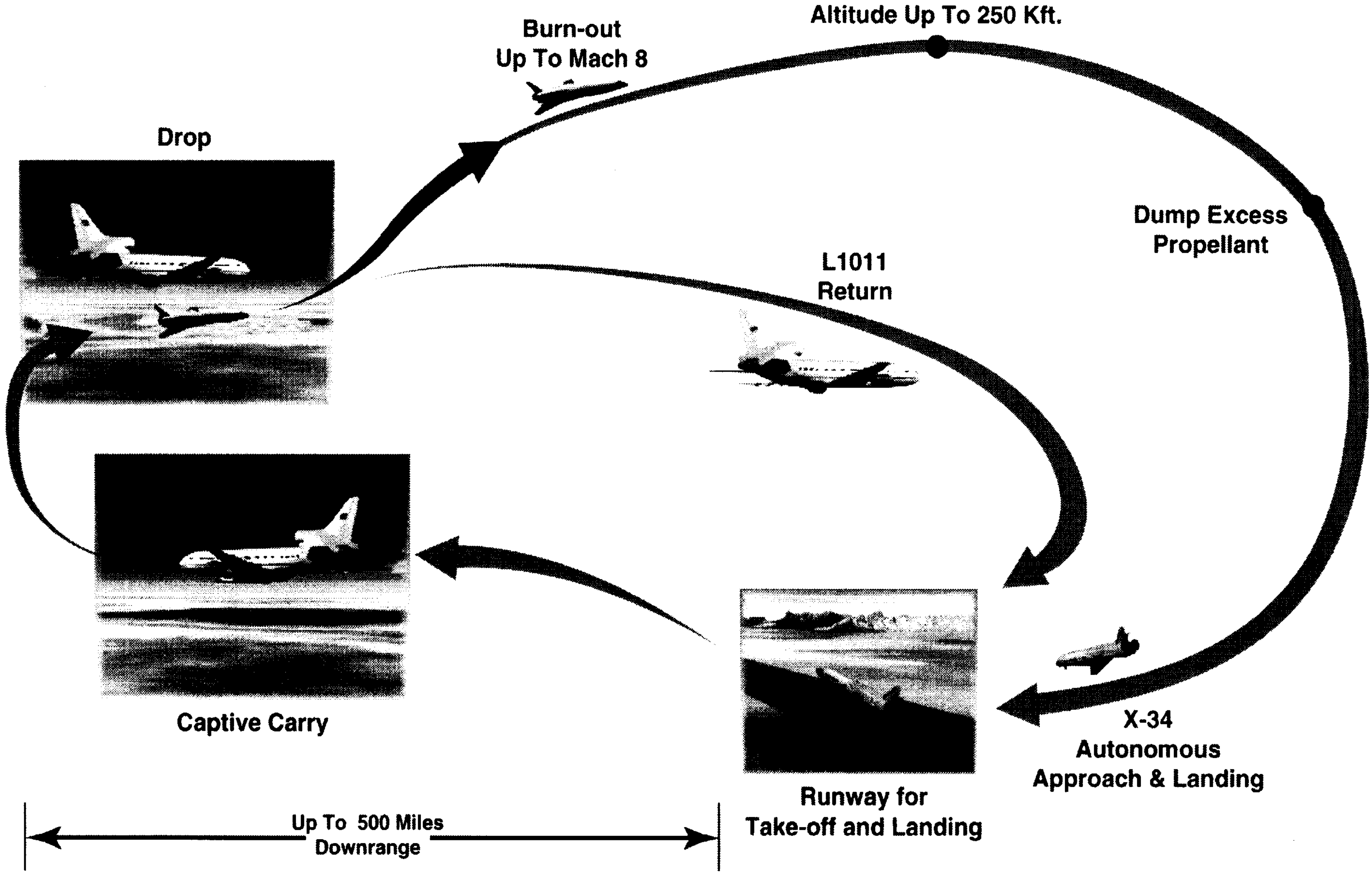
- **Low cost operations capable of demonstrating safe abort**
  - Small work force
  - Nominal 2-week turnaround
  - Surge capability of 2 flights within 24 hours
  - Capable of attaining average recurring flight cost of $500k
- **Operation in RLV-type environments**
  - Flights through rain and fog
  - Landings with cross winds of 20 knots or greater



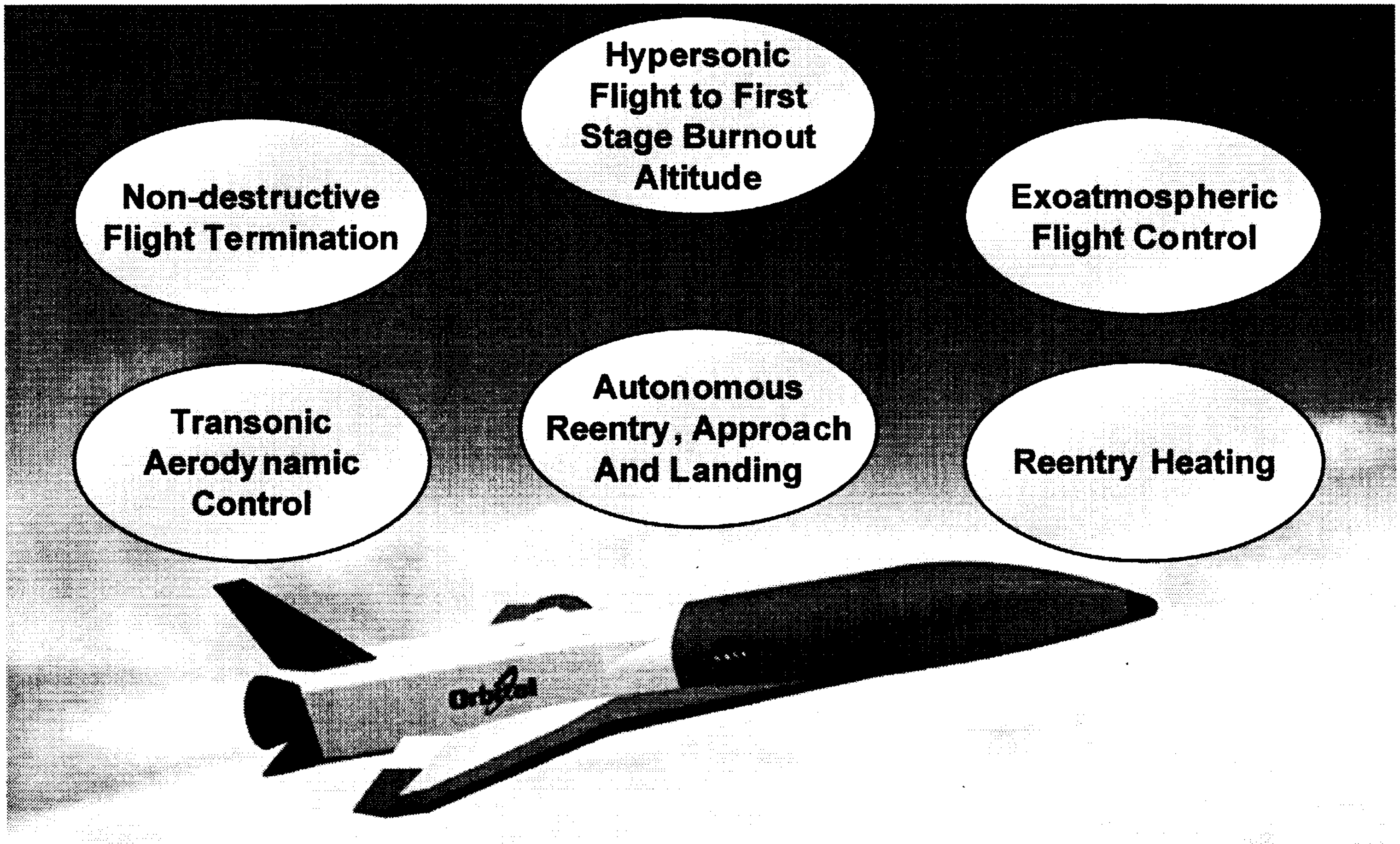
Testbed for Hosted RLV and Hypersonic Experiments

- **On-board instrumentation for testing embedded technologies**
- **Small area for "carry-on" experiments**

X-34 Typical Mission Profile

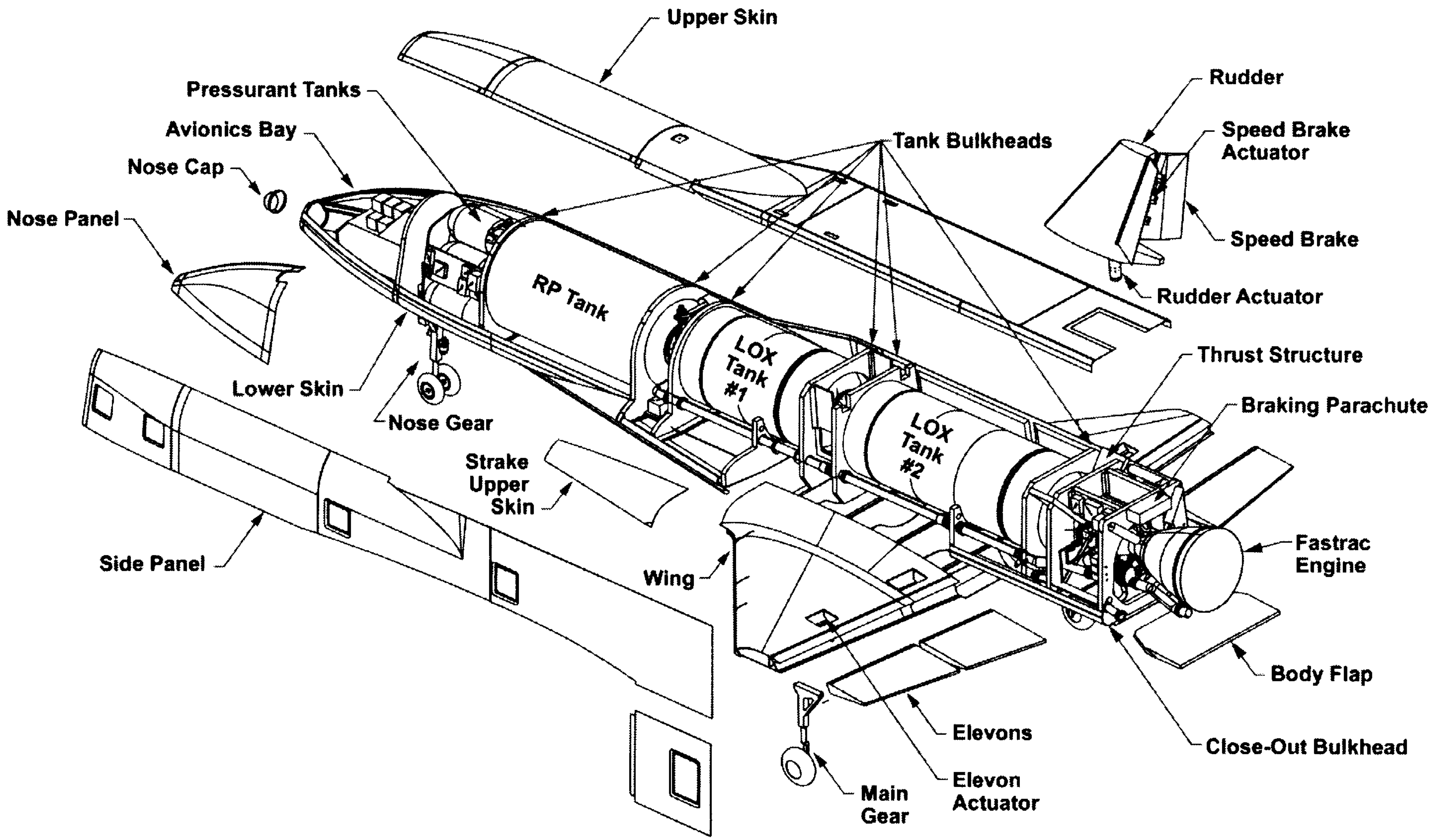


Flight Testing for a Multistage Reusable System

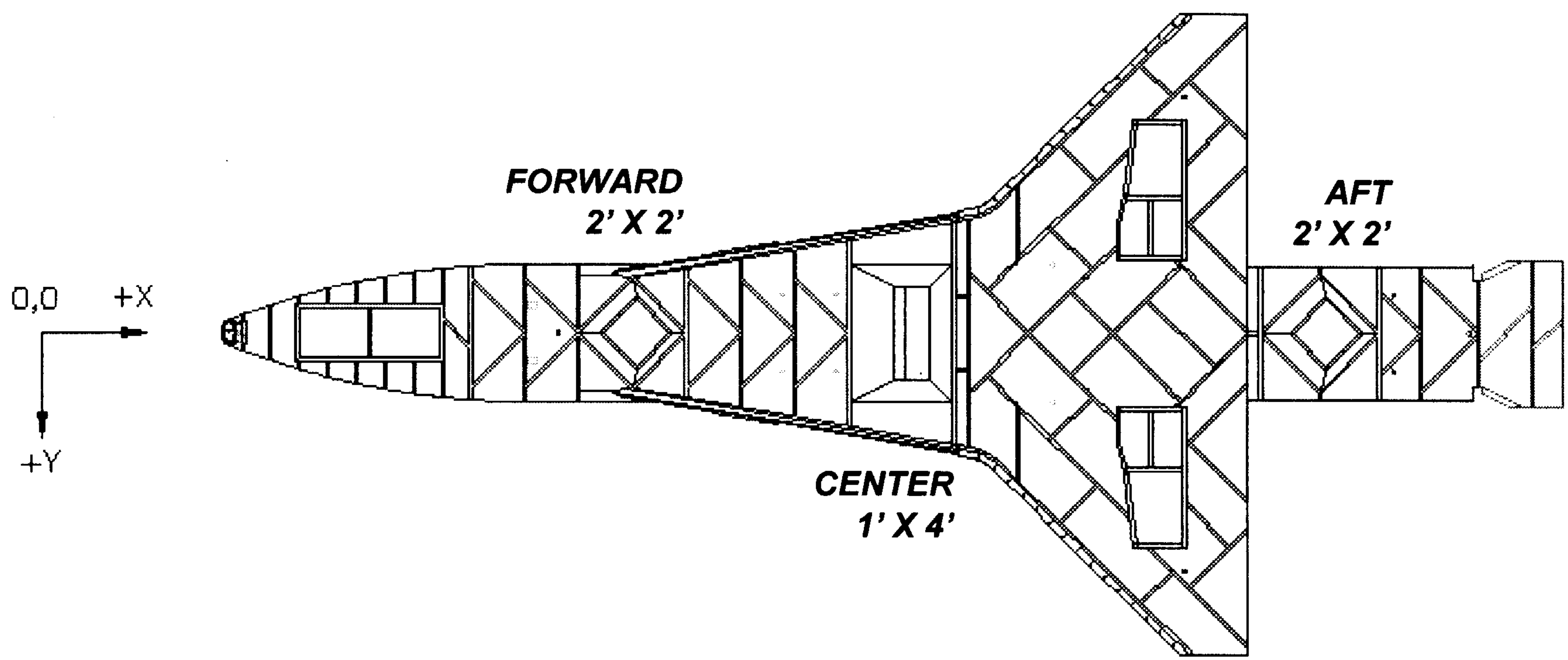


The X-34 Flight Regime Duplicates the Environment and Mission Characteristics Of a Reusable First Stage

X-34 Expanded View

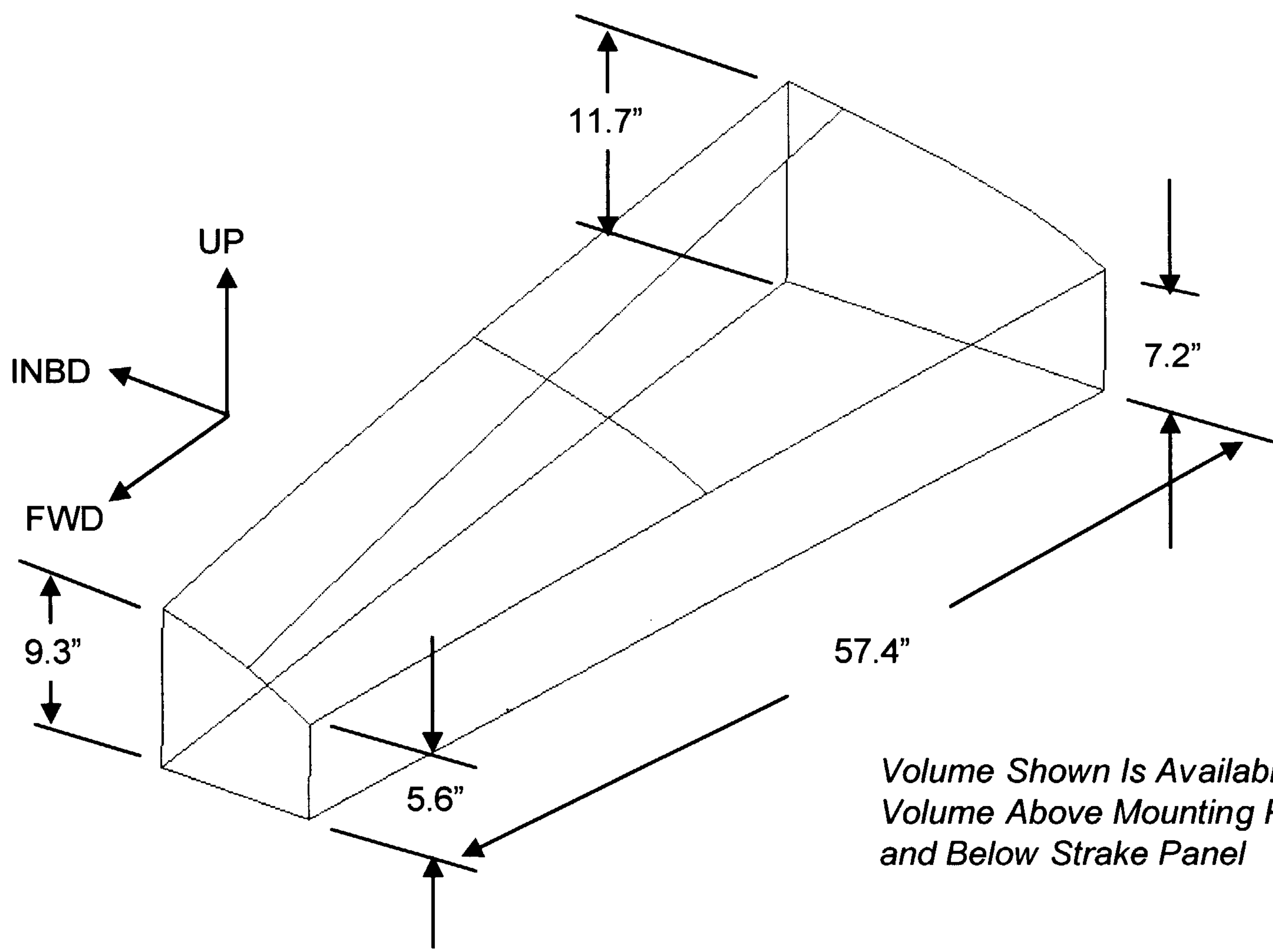


X-34 TPS Attach Points



X-34 Payload/Experimentation Volume

Strake Volume Available



Volume Shown Is Available Volume Above Mounting Panel and Below Strake Panel

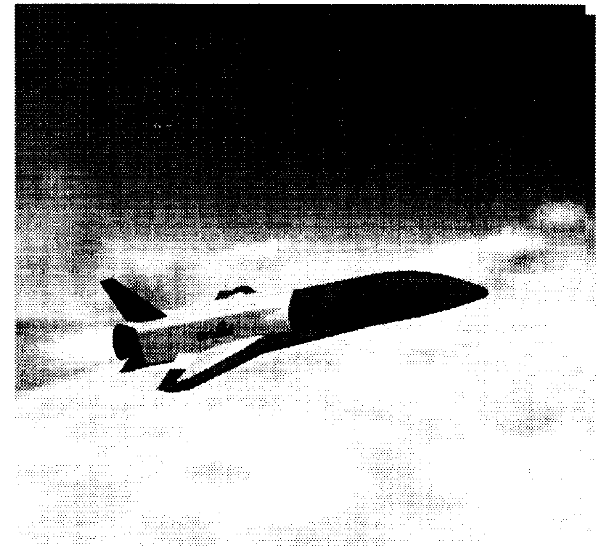
Pathfinder Experiments on X-34

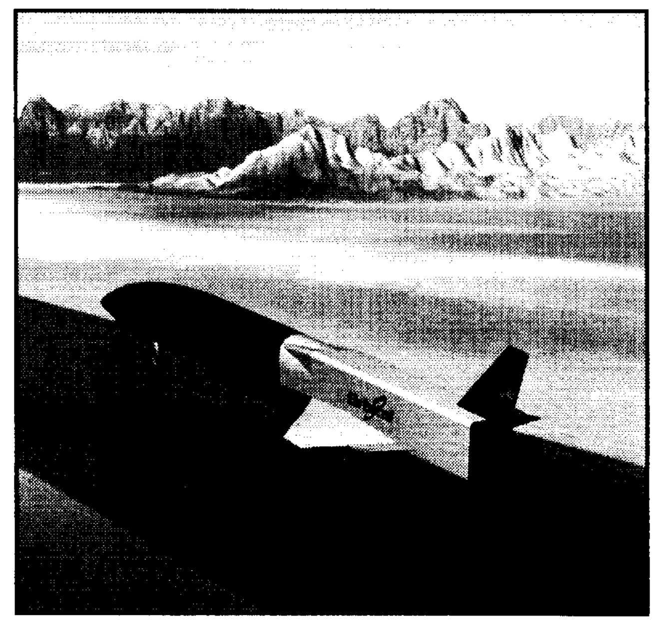
- **X-34 Rocket Plane - Atmospheric technology testbed Flight Experiments**

Base-lined X-34 Experiments
- Active Damage Interrogation Health Monitoring System
- Acoustic Emission Health Monitoring System
- Autonomous Abort Landings
- Integrated Vehicle Health Management (IVHM)
- Unlined Composite LOX Tank

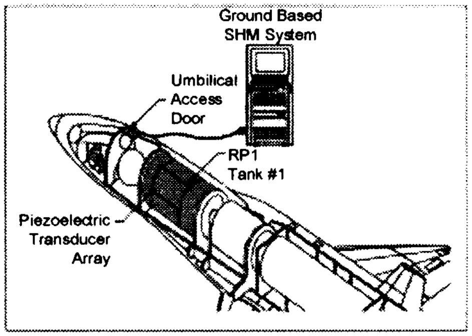
Reviewing Proposals on:
- Base Drag (DFRC)
- Range Safety (Goddard, KSC)

Efforts currently on hold:
- Gamma-Titanium Aluminum-Based TPS
- Advanced C/SIC TPS
- Mechanically Attached Flexible TPS
- Encapsulated Waterproof 2500°F CMC TPS
- Flight Test Detailed Specimens In Certified Holder

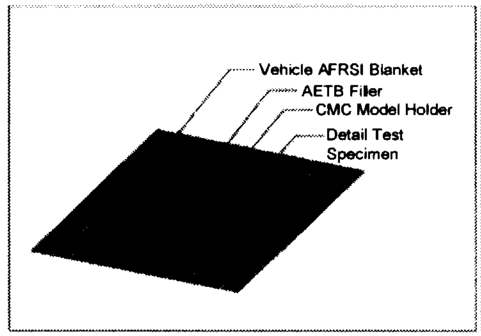




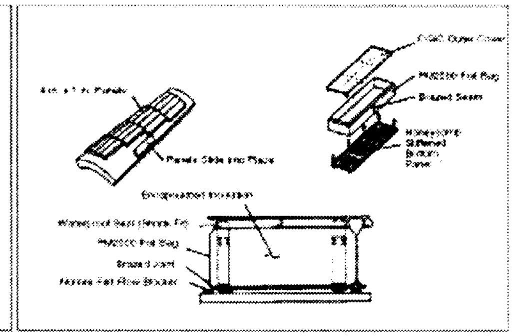
Original Baseline Experiments



Integrated Structural Health Monitoring System for the X-34 RP1 Tank (Boeing, St. Louis).

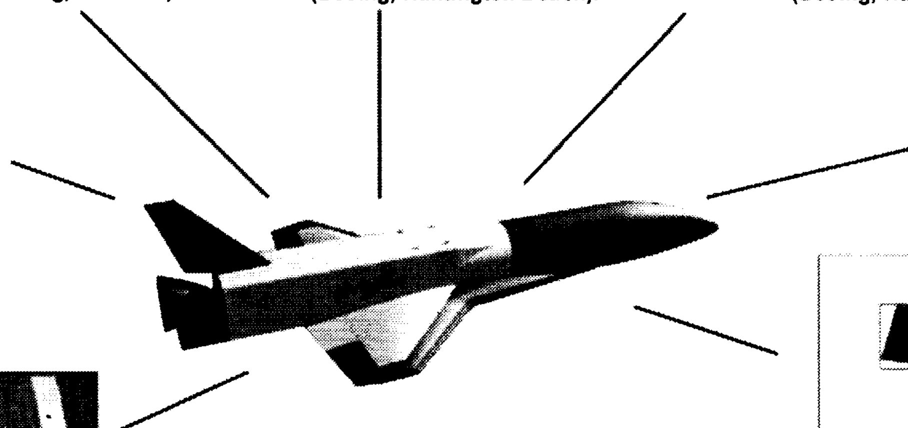


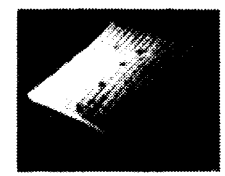
Detail Test Specimen Model Holder (Boeing, Huntington Beach).



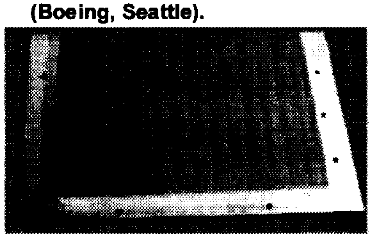
CMC Encapsulated TPS Assembly (Boeing, Huntington Beach).

Acoustic Emission Health Monitoring System (Boeing, Seattle).

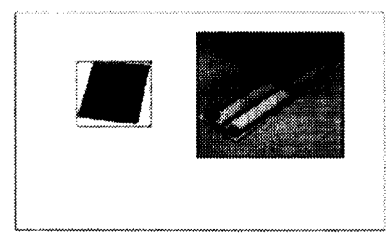




IFI Blanket
TiAl Based TPS (Alenia, Italy)



Mechanically Attached Thermal Protection System (Boeing, Seattle).



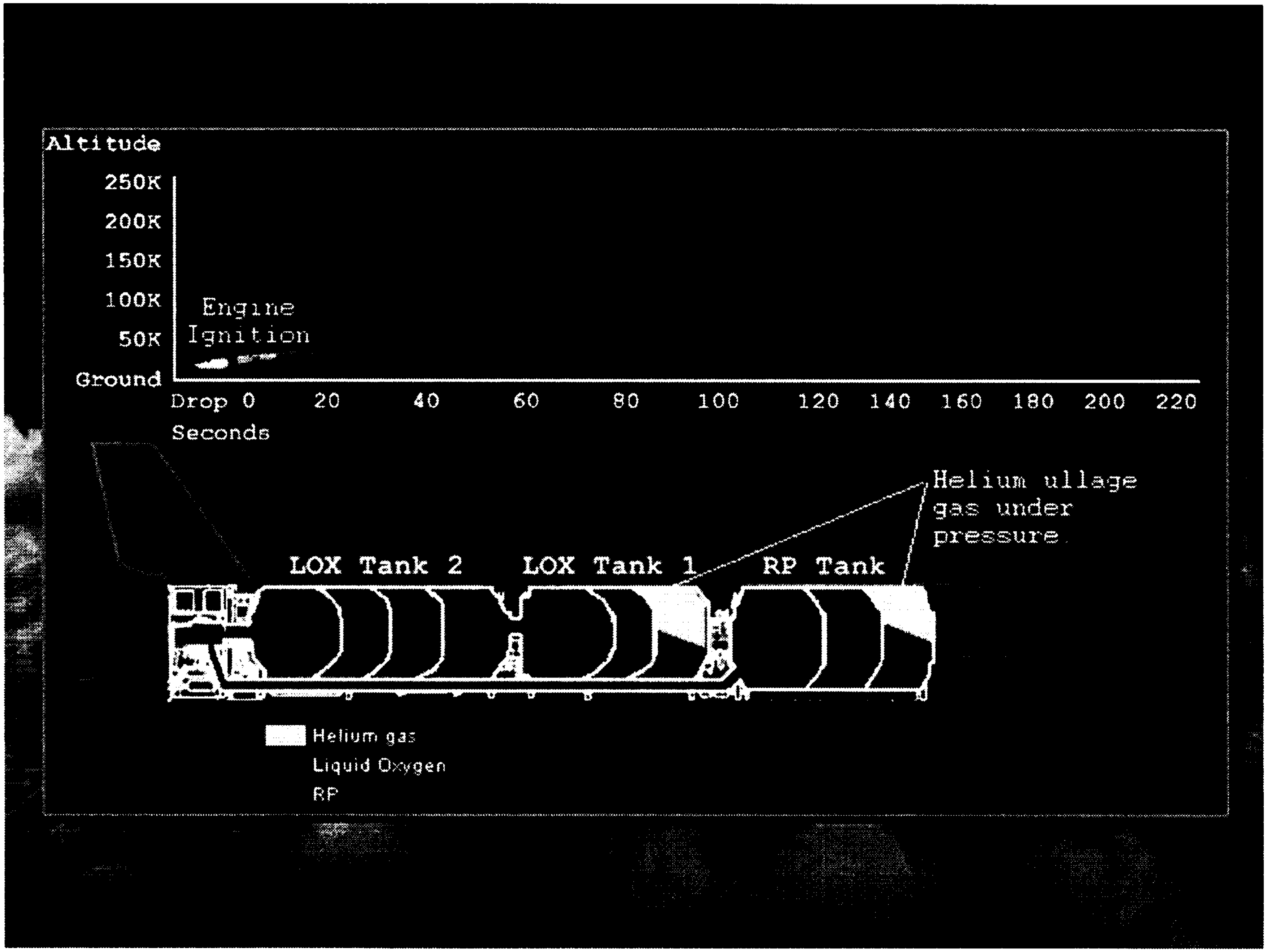
Advanced C/SiC Based TPS (Daimler Benz, Germany).

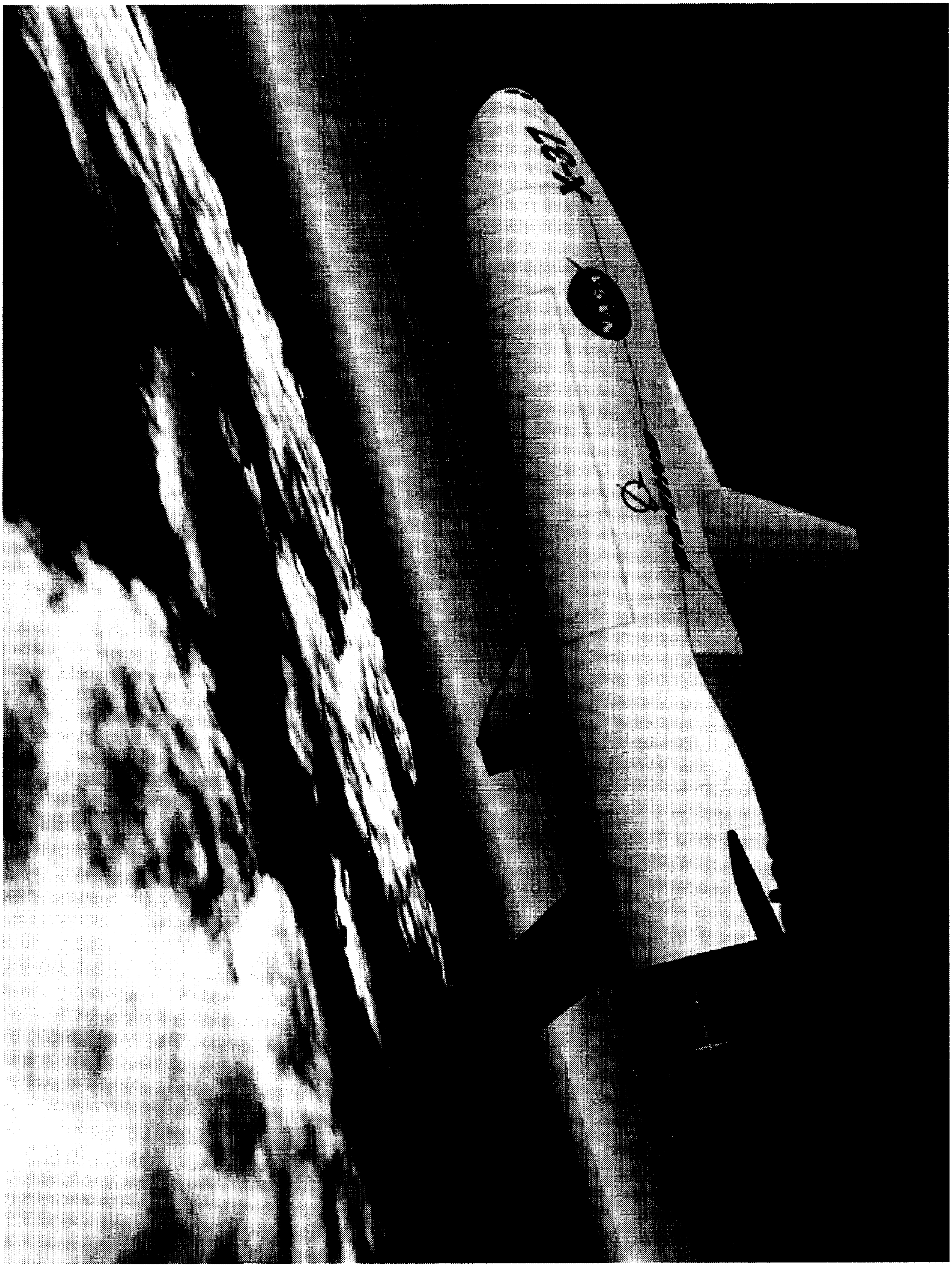
X-34 Flight Experiments

- **Autonomous Abort Landings**
  - Technology-- Development and integration of onboard Real-Time mission planning and robust guidance and control for low mach flight. Will reduce number of ground personnel for flight planning and reduce risk of vehicle loss in aborts.
  - Description -- Software package. After demo it will be permanent part of operational software. To be flown on X-34 in latter stages of the currently scheduled test flight series.
  - Team Members
    - Industry: Draper Lab
    - NASA: MSFC (Lead)
- **Integrated Vehicle Health Management (IVHM)**
  - Technology-- Experiment will integrate components that have been separately developed to build an integrated VHM capability. Will lead to reduced turnaround time and ops cost of RLV's.
  - Description -- Components include Propulsion system diagnostic/prognostic system, RLV Engine monitoring system, Condition-based monitoring, and data fusion. To be flown on X-34 Vehicle.
  - Team Members
    - Industry: Orbital Sciences Corporation
    - NASA: ARC (Lead), KSC, GRC, & MSFC

X-34 Flight Experiments (cont'd.)

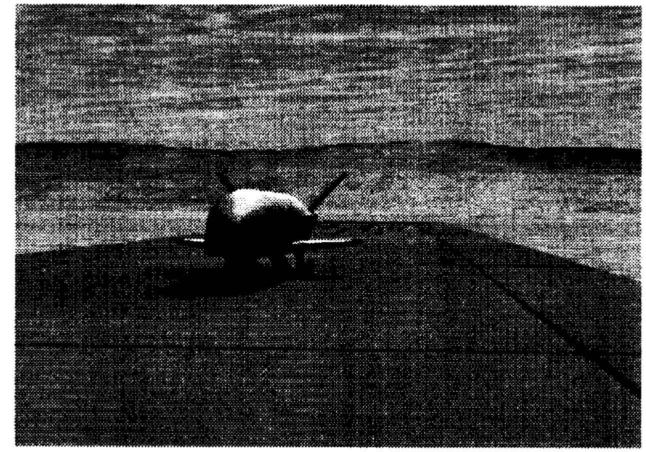
- **Composite LOX Tank**
  - Technology-- Reusable composite Liquid Oxygen tank demonstrated in relevant environments.
  - Description -- A composite Liquid Oxygen tank will be developed and integrated into the X-34 technology demonstrator vehicle. The tank will be flown in relevant environments and reused a number of times.
  - Team Members
    - Industry: Lockheed-Martin (Lead), Orbital Sciences Corporation
    - NASA: MSFC, JSC White Sands Test Facility


Altitude
250K
200K
150K
100K
50K
Ground
Engine
Ignition
Drop 0
20
40
60
80
100
120
140
160
180
200
220
Seconds
Helium ullage
gas under
pressure
LOX Tank 2
LOX Tank 1
RP Tank
Helium gas
Liquid Oxygen
RP

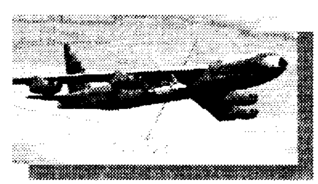


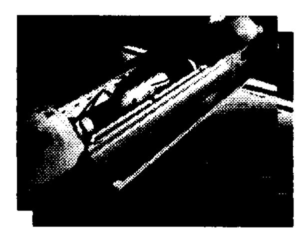
X-37 Project Overview

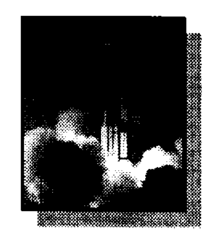
- **Project Objective**
  - Demonstrate technologies required to reduce the cost of access to and operations in space
- **Key Features**
  - Designed to close current X-Vehicle gap
  - Addresses both Earth-to-Orbit (TA-1) and Orbit-to-Orbit (TA-2) technologies in single testbed vehicle
  - Modularized for rapid insertion of broad range of technologies and experiments
  - Flight test program follows progressive envelope expansion -- launch options include:
    - B-52, Shuttle, ELV



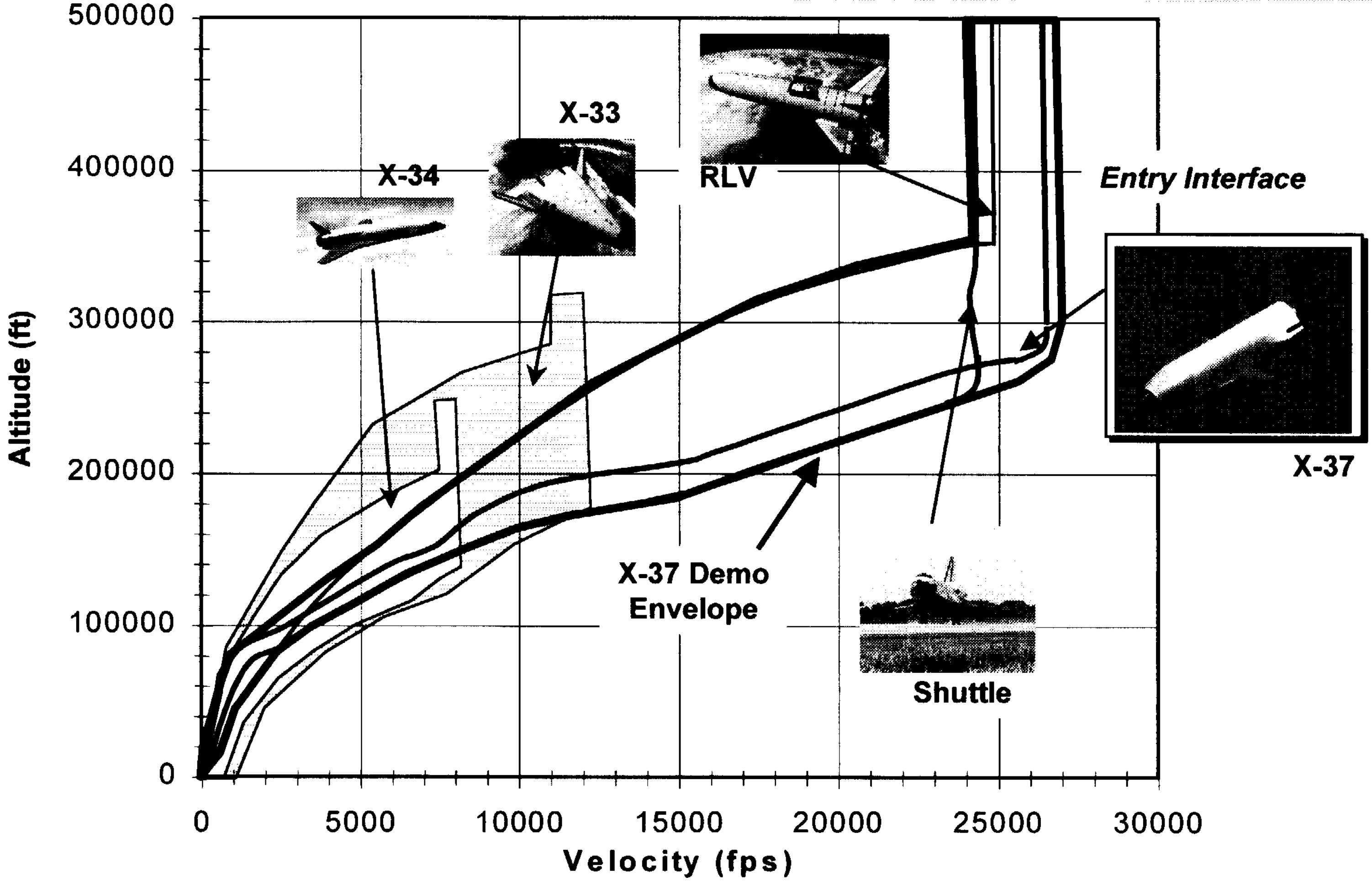
Fuselage Length (ft)	25.7
Wing Span (ft)	14.4
Baseline Payload (lb)	500
Entry Weight (lb)	5,800
GLOW (lb)	13,090







X-37 Extends the Testbed Envelope to Orbital Capability

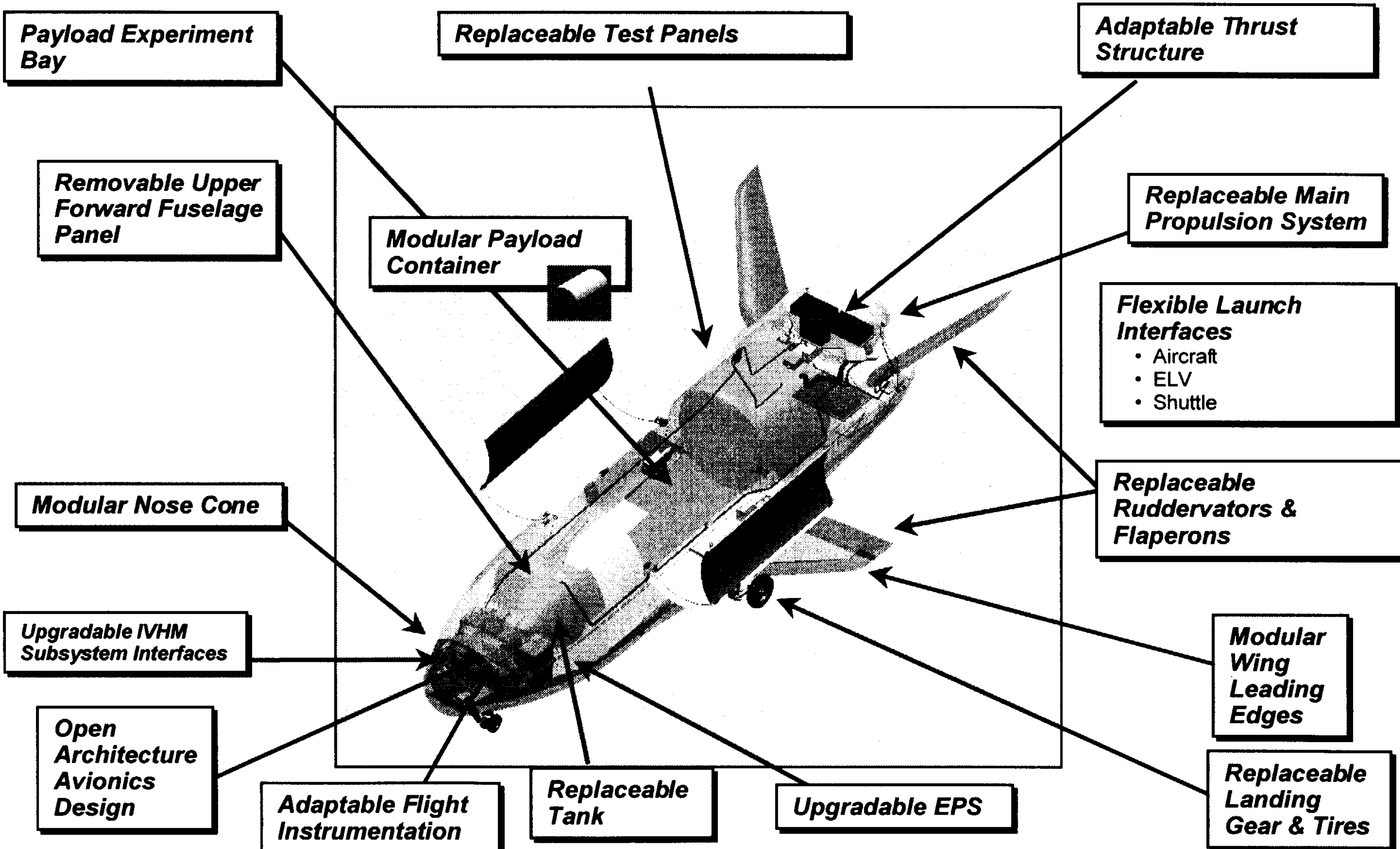


- ♦ **X-37 Provides Orbital and Re-entry Test Capability**
  - Reentry trajectory can simulate TSTO 2nd stage environment
  - Autonomous operations (maneuver and rendezvous)
  - Long-term on-orbit demonstrations (2-21 days)
  - Advanced TPS for reusable space vehicles
  - Designs/manufacturing techniques traceable to larger reusable systems

Mission Capability

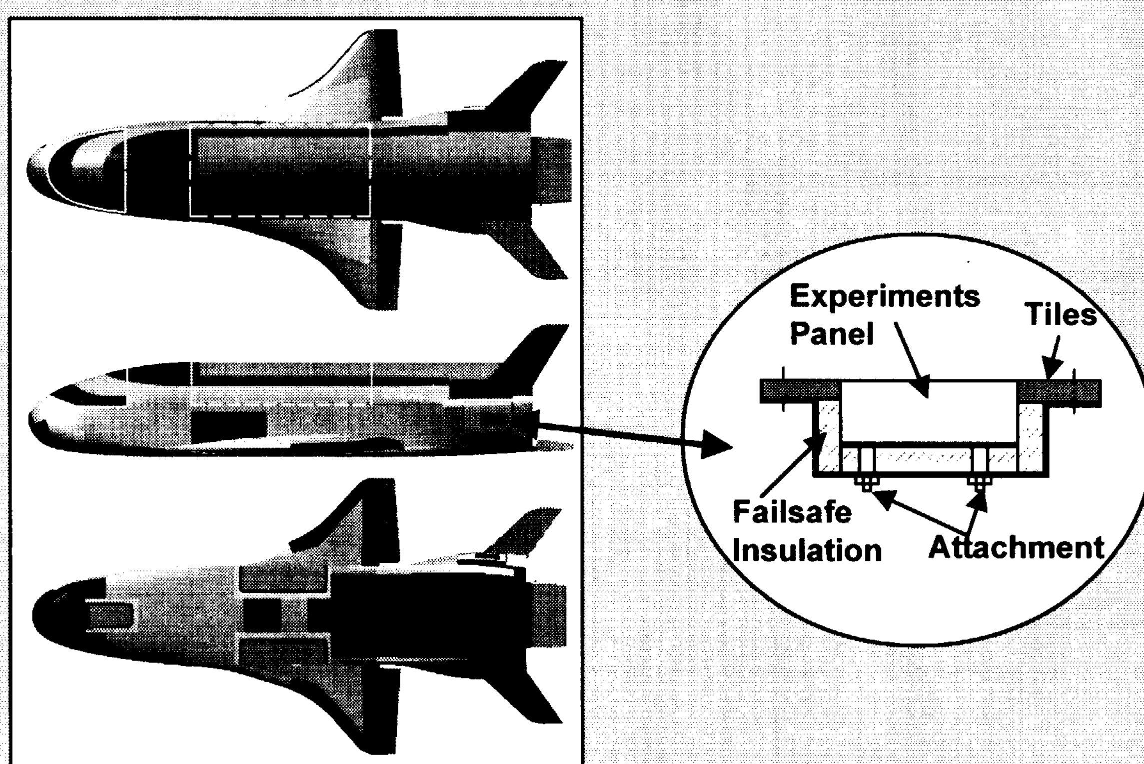
- **Inclination: 28.5 to 57 degrees (per sys spec & MCR X37-99-0011)**
  - Solar Beta Angle = 0 to 80.5 degrees (derived from above & R460)
- **Orbit Altitude**
  - 100 to 470 nm (R460)
- **Duration**
  - Nominal 21 days + 5 days contingency (R459)
  - In shuttle cargo bay 2 days nominal + 5 days contingency, 10 days max (R461)
- **Pointing Accuracy**
  - 3 Axis stabilized
  - PRCS On Orbit Attitude Accuracy : ± 3.0 degrees (3 sigma) and ± 0.5 deg/sec (3 sigma), respectively, each axis. (GN&C B-spec)
  - VRCS On Orbit Attitude Accuracy ± 0.5 degrees (3 sigma) and ± 0.05 deg/sec (3 sigma), respectively, each axis. (GN&C B-spec)

X-37 Modularity Readily Supports Rapid Technology Insertion and Experiments



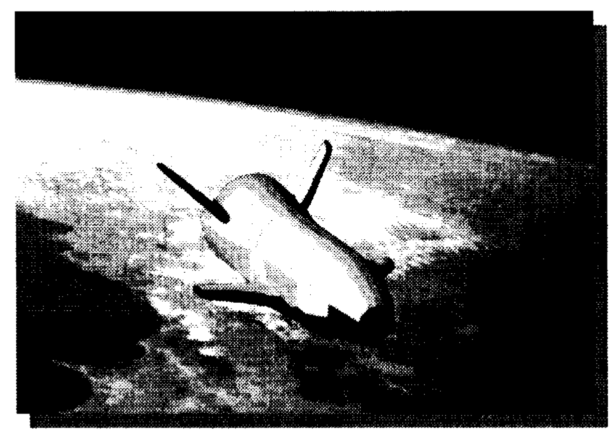
Failsafe TPS Test Panel

Objective:
The objective is to provide a fail-safe TPS screening test panel to test various potential TPS concepts (face sheets/stack-ups, structures/TPS and hot structures), in on-orbit and reentry/aeromaneuvering environments.

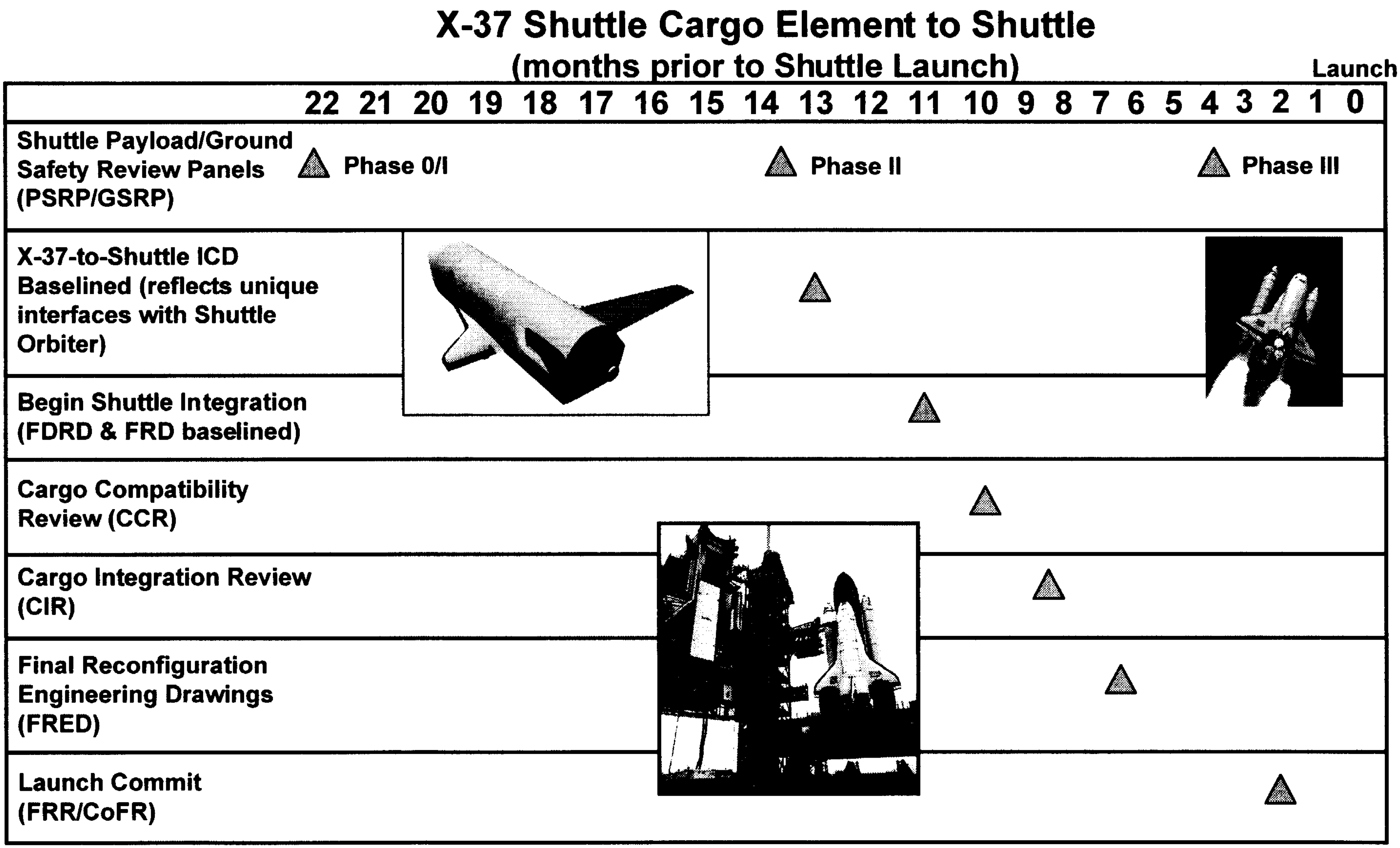


X-37 Overview

- X-37 Payload Integration Schedules
- X-37 Payload Safety
- X-37 Payload Environments
- X-37 Payload Interfaces & Services

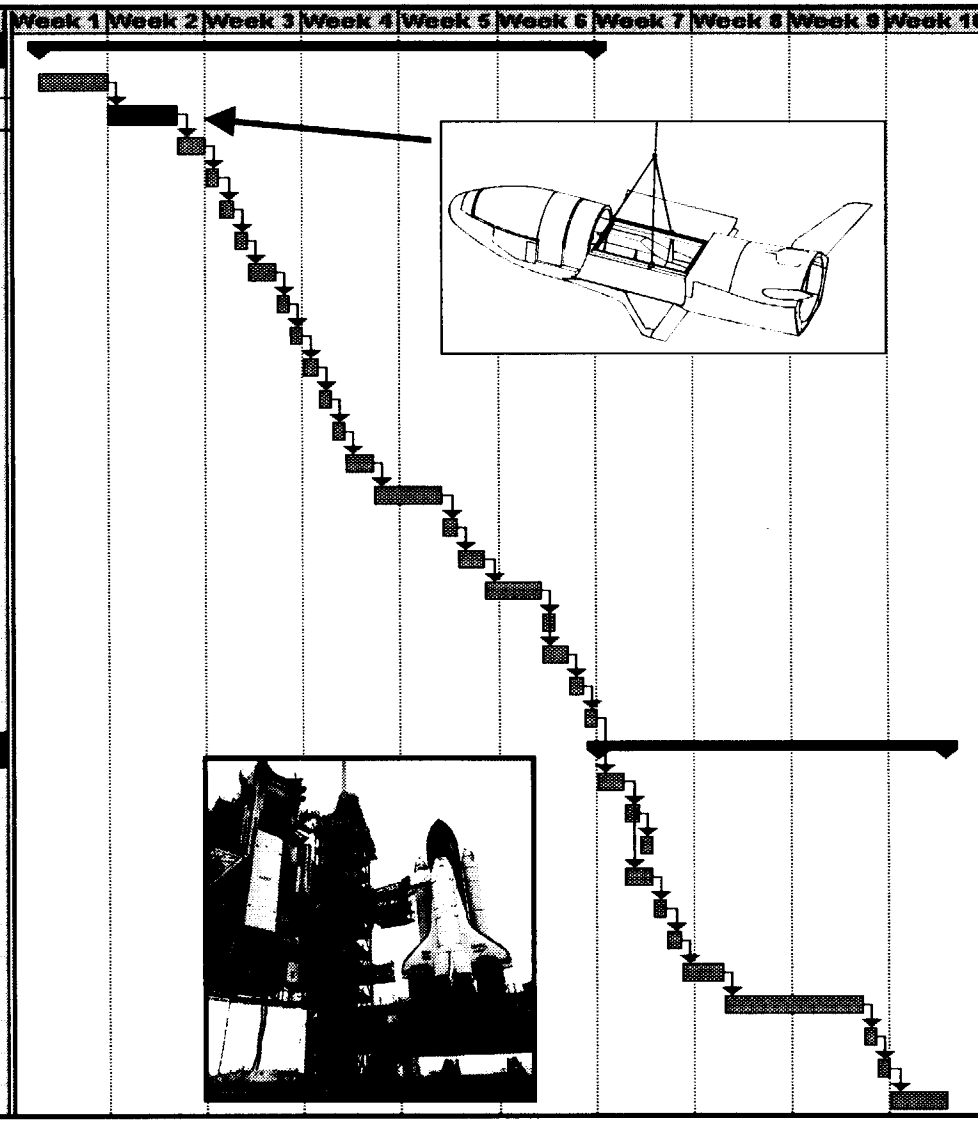


X-37 Payloads Need to Support X-37/Shuttle Orbiter Integration Milestones



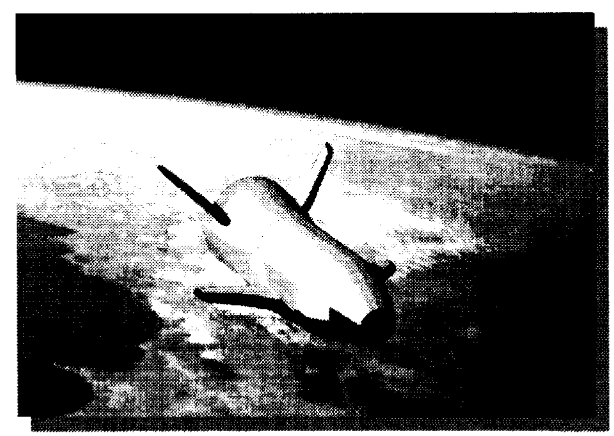
X-37 Payload Installation Occurs 9 Weeks Prior to Launch

ID	Task Name	Duration
	− X-37 Offline Preps in VPF	40 days
2	Receive and inspect X-37 and GSE	5 days
3	Install and test payload experiments	5 days
4	Prep X-37 for mate to cradle & pallets	2 days
5	Mate X-37 to cradle (pallets in P/L canister)	1 day
6	Mate X-37-to-cradle electrical umbilical	1 day
7	Setup test equipment and connect test cabl	1 day
8	Cradle integration electrical test	2 days
9	Disconnect test cables and stow test equip	1 day
10	Close canister & move to CRF	1 day
11	Rotate canister to vertical	1 day
12	Move canister to VPF & prep for P/L transfe	1 day
13	Transfer X-37/pallets into VPF test cell	1 day
14	Test cable and SIP connections	2 days
15	X-37/cradle CITE testing	5 days
16	Astronaut EVA tool verification	1 day
17	Install propellant loading GSE	2 days
18	Load X-37 propellants and stabilize	4 days
19	Remove propellant loading GSE	1 day
20	Test cable and SIP disconnections	2 days
21	Prepare X-37/pallets for transport	1 day
22	Transfer X-37/pallets into P/L canister	1 day
	− X-37 Launch Pad Activities	25 days
24	Transport X-37/pallets to pad & install in PG	2 days
25	Configure access platforms	1 day
26	Prepare X-37/pallets for installation	1 day
27	Shuttle transfer and mate to pad	2 days
28	Install X-37/pallets into Orbiter P/L bay	1 day
29	Configure access platforms	1 day
30	Orbiter-to-payload integrated testing	3 days
31	Misc. Shuttle prelaunch activities (dwell tim	10 days
32	Connect X-37/cradle ordnance	1 day
33	Pull S&A pin, disc. vent, closeout for flight	1 day
34	Close P/L bay doors; countdown & launch	4 days



X-37 Overview

- X-37 Payload Integration Schedules
- X-37 Payload Safety
- X-37 Payload Environments
- X-37 Payload Interfaces & Services



X-37 Payload Safety Requirements

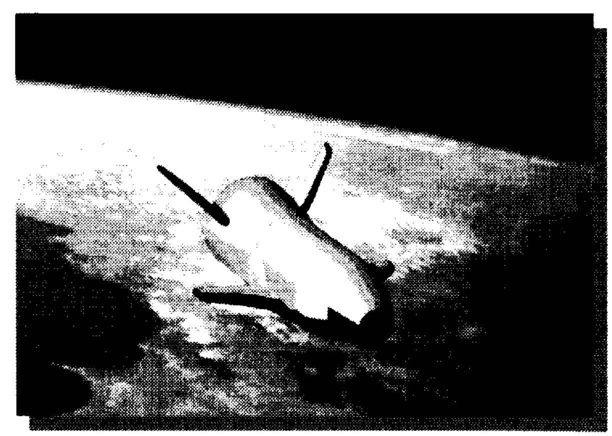
- **X-37 Payloads Must Satisfy the Following Requirements:**
  - SP877-0001, "Safety Policy for Payloads Using the X-37 Flight Demonstration Vehicle for X-37 Program Space Shuttle Flights."
  - SP877-TBD, "Ground Safety and GSE Safety Policy and Requirements for Payloads Using the X-37 Flight Demonstration Vehicle for X-37 Program Space Shuttle Flights."
- **Two Basic Safety Requirements of these Documents:**
  - Catastrophic hazards shall be controlled such that no combination of two failures or operator errors can result in the potential for a disabling or fatal personnel injury or loss of the Orbiter, ground facilities or STS equipment.
  - Critical hazards shall be controlled such that no single failure or operator error can result in damage to STS equipment, a nondisabling personnel injury, or the use of unscheduled safing procedures that affect operations of the Orbiter or another payload.

X-37 Payloads Need to Provide Supporting Safety Documentation for Safety Reviews

- **Supporting Safety Documentation from the X-37 Payload Organization Will Be Required to Support X-37 Vehicle Payload Safety Review Panel (PSRP) and Ground Safety Review Panel (GSRP) Safety Data Package (SDP) Development and Reviews.**
  - The X-37 Vehicle Organization Will Require Supporting Safety Documentation 90 Days Prior to the X-37 Vehicle PSRP and GSRP Reviews (Reference Attached X-37 Tentative Vehicle PSRP/GSRP Schedules).
    - The X-37 Vehicle organization will conduct a review with the X-37 Payload Organization of this supporting documentation prior to its incorporation into the X-37 Vehicle PSRP and GSRP SDPs.
- **Supporting Safety Documentation from the X-37 Payload Organization Will Also Be Required to Support Safety Assessment Report (SAR) Development and Appropriate Range Safety Reviews.**

X-37 Overview

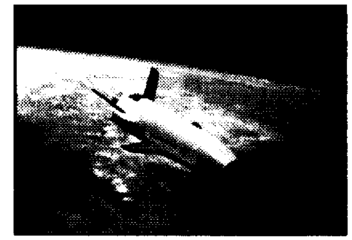
- X-37 Vehicle Summary
- X-37 Payload Integration Schedules
- X-37 Payload Safety
- X-37 Payload Environments
- X-37 Payload Interfaces & Services

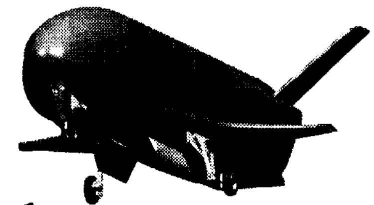


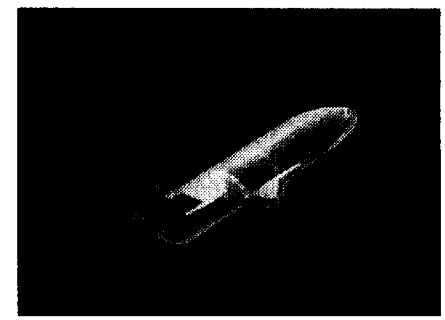
Payload Environments are Under Development Based On Launch, On-Orbit and Reentry Phases

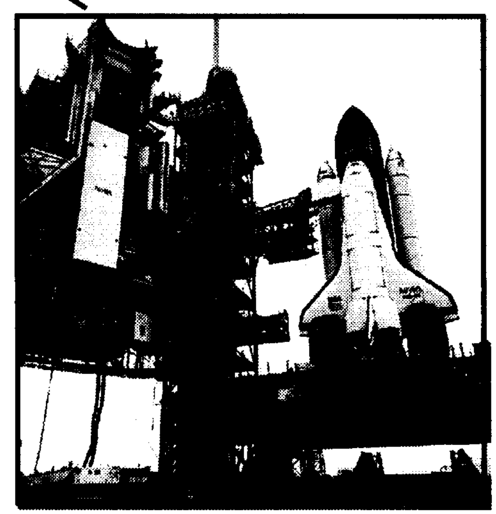
Payload Environments

- **Prelaunch Environments**
  - Air conditioning
  - Radiation & electromagnetic environments
  - Electrostatic potential
  - Contamination and cleanliness
- **Launch & Flight Environments**
  - Payload bay internal pressure
  - Thermal environment
    - Launch
    - On-orbit
    - Reentry
  - Flight Dynamic Environment
    - Steady state acceleration
    - Combined Loads
    - Acoustic Environment
    - Sinusoidal Vibration Environment
    - Shock Environment







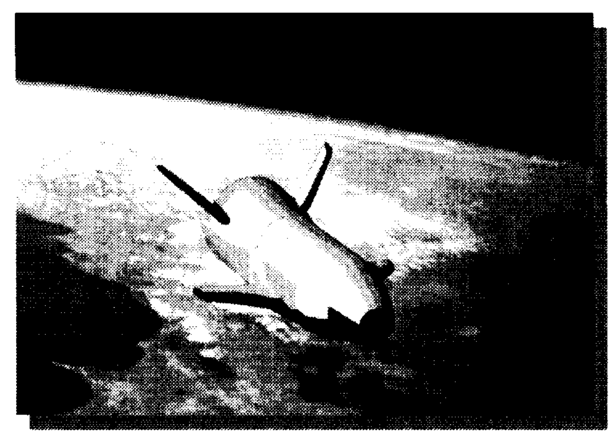


X-37 Payload Environments

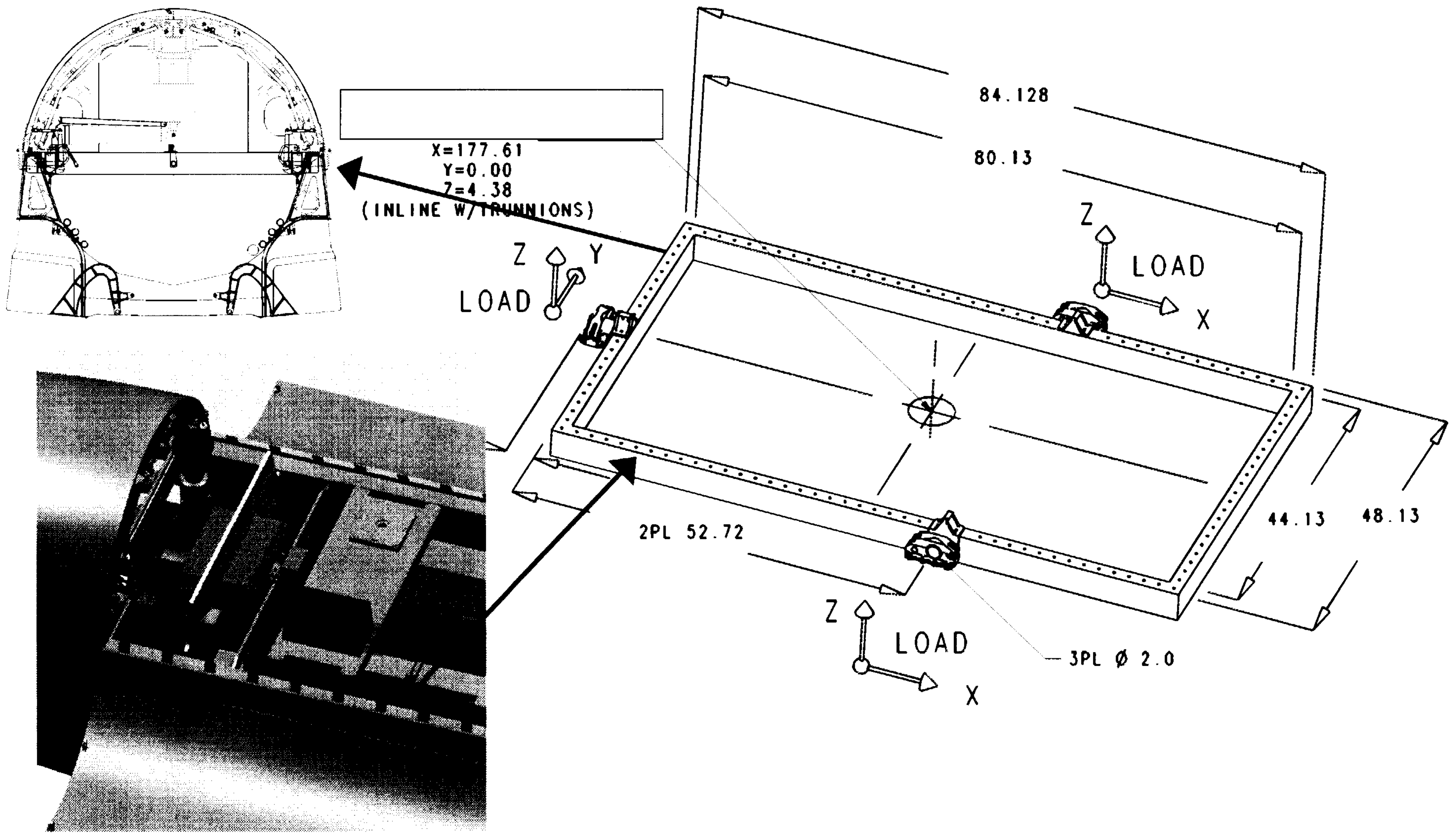
- **Radiation Environments**
  - Compatible with inclination and altitude range specified in mission capability chart
- **Random Vibration & Acoustic Environments**
  - Must be compatible with Shuttle ascent, Pyro separation shock loads, and entry environments
  - Available through Boeing
- **Acceleration**
  - Must be compatible with Shuttle ascent, on-orbit, and entry environments
  - Available through Boeing

X-37 Mission 1 and 2 Payload Overview

- **X-37 Payload Integration Schedules**
- **X-37 Payload Safety**
- **X-37 Payload Environments**
- **X-37 Payload Interfaces & Services**



X-37 Payload Container Frame and Interface Definition



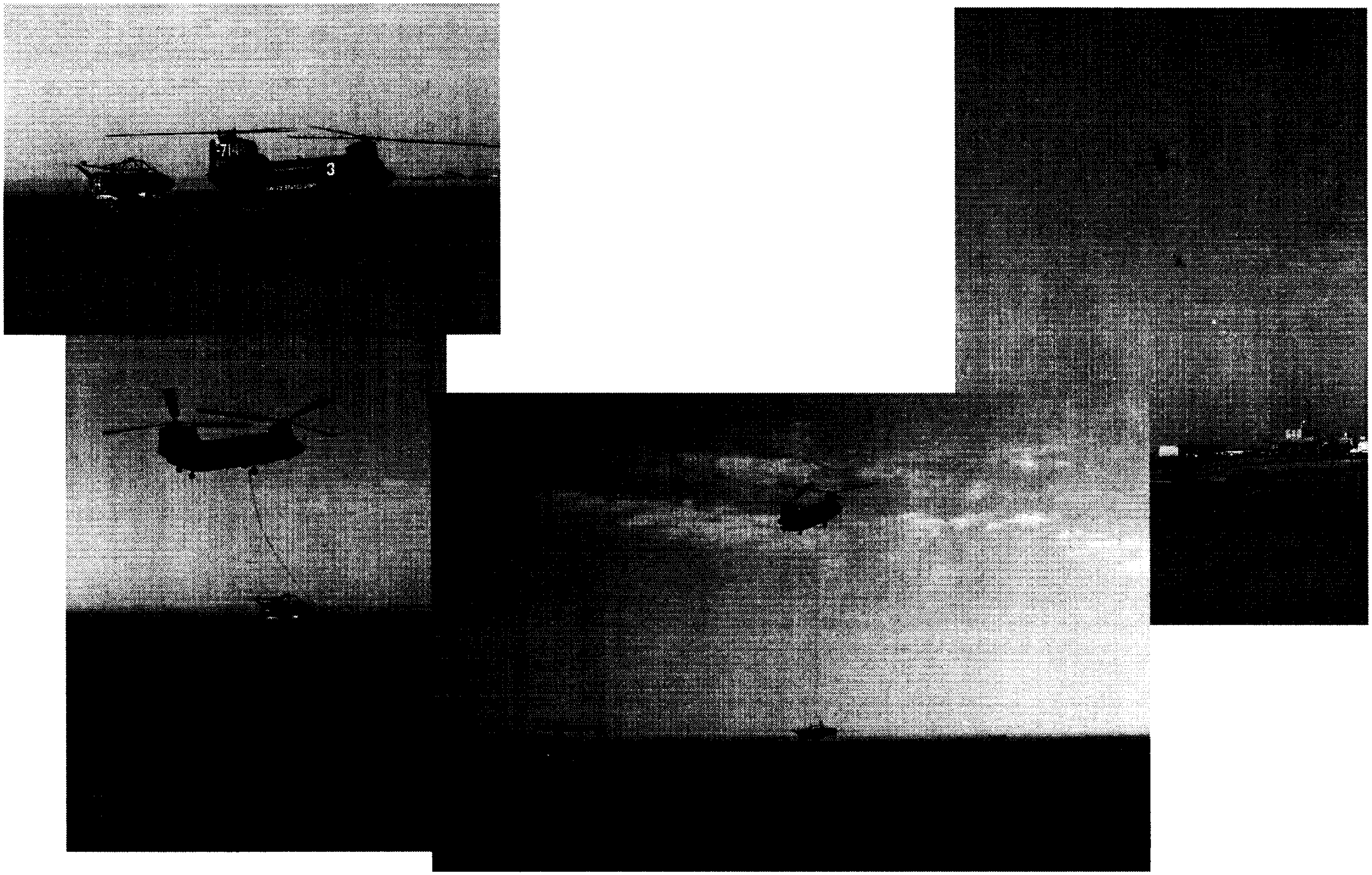
X-37 Payload Power and Avionics

- **On-orbit Power:**
  - Voltage: 28 VDC
  - Power: 100 Watts orbit average supplied from X-37
    - Payload is responsible for power requirements beyond 100 Watts average
- **Reentry Power:**
  - Voltage: 28 VDC
  - Power: payload is responsible for power requirements
- **Number of Channels: TBD**
- **Telemetry**
  - High data rate Ku band antenna: 5 Mbps (peak)
- **Data Storage**
  - Vehicle Management Computer (VMC)
- **Possible X-37 Payload Communication Interfaces Include:**
  - 1553
  - RS422
  - 1773

Integrated X-37/X-37 Payload Testing

- **Payloads integrated with the X-37 shall meet the requirements of NASA-STD-7002 or MIL-STD-1540C Tailored.**
- **Payload shall supply the necessary equipment for integrated testing and servicing.**

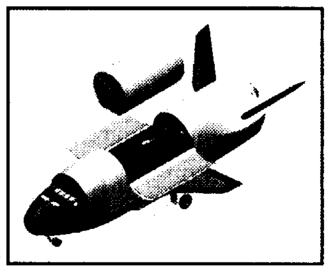
X-40A Flight Test Vehicle Summer 00



43 Technologies and Experiments Have Been Identified for Follow-On Demonstration

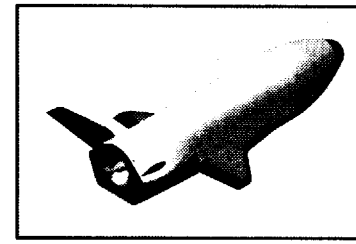
Reusable Launch/Space Vehicle Technology Testbed

- Propulsion
  - Alternate main engines and propellants
  - Improved lines/valves
  - Extended on-orbit life and operations
- Airframe
  - Interchangeable tankage
  - Alternate wings and control surfaces for concepts and materials
  - Advanced, light weight landing gear (extended on-orbit capability)
- VMS/Avionics
  - Flight diagnostics and prognostics adaptation
  - Modular insertion of advanced avionics upgrades
  - Sub-surface Ka-Band phased array antenna
  - Air data systems
- IVHM
  - Autonomous operations
  - Extended to all subsystems
- TPS
  - Lighter weight, more robust and capable materials
  - Improved installation techniques and test procedures
- EPS
  - Fuel cells
  - Turbo-alternators and supercapacitors
  - Flywheels
- Light Weight, Flexible Structures
  - C/C payload experiment bay doors integrated with radiators
  - Deployable, retractable solar arrays
  - Deployable, retractable antennas



Reusable Launch/Space Vehicle Operations Testbed

- TSTO separation systems
- Improved operations, maintenance and repair concepts/procedures to reduce turn time
- Automated rendezvous, capture and proximity operations
- Automated aeroassist and aerobraking using closed-loop data feedback
- Satellite servicing and repair
- Satellite refueling
- Debris cataloging and removal
- On-orbit payload changeout



Upper Atmosphere Testbed

- Global sampling and in-situ validation to support model development and forecasting

Expendable Spacecraft Technology Testbed

- Bus subsystems and components
- Payload/instrument elements (e.g., imagers)

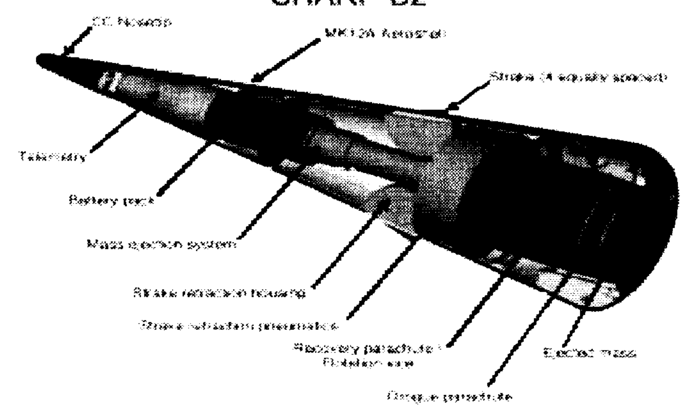
Space Exploration Technology Testbed

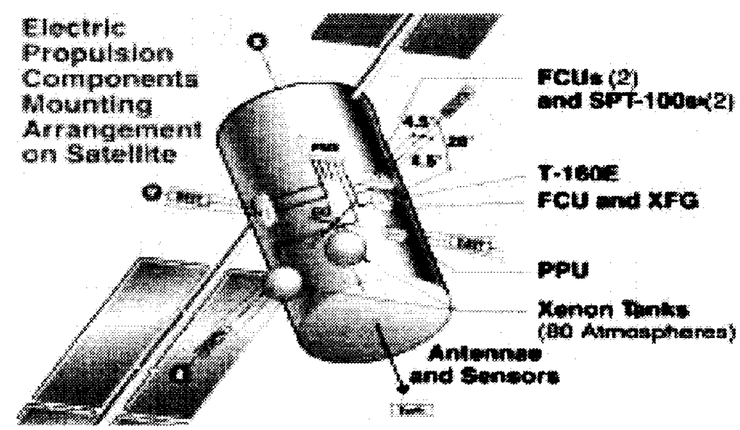
- Lunar exploration(including surface sample return)
- Technologies for interplanetary orbiters, landers, rovers, penetrators

Other Pathfinder Experiment

- **Flight Experiments**
  - Other Flight Experiments:
    - REDUCED COST SMALL PAYLOAD TECHNOLOGIES (AERO-ASTRO)
      - Deployed from the Space Shuttle
    - CERAMICS FOR SHARP LEADING EDGES (NASA AMES)
      - Flown on a Minuteman III
    - ProSEDS (NASA MSFC)
      - Flown as a secondary payload on a Delta II upper stage
    - HALL EFFECT THRUSTER (NASA GRC)
      - Flown on a Russian Communications Satellite
    - CRYOGENIC PROPELLANT GAUGE (NASA GRC)
      - Flown on the USAF Solar Orbit Transfer Vehicle Space Experiment

SHARP-B2



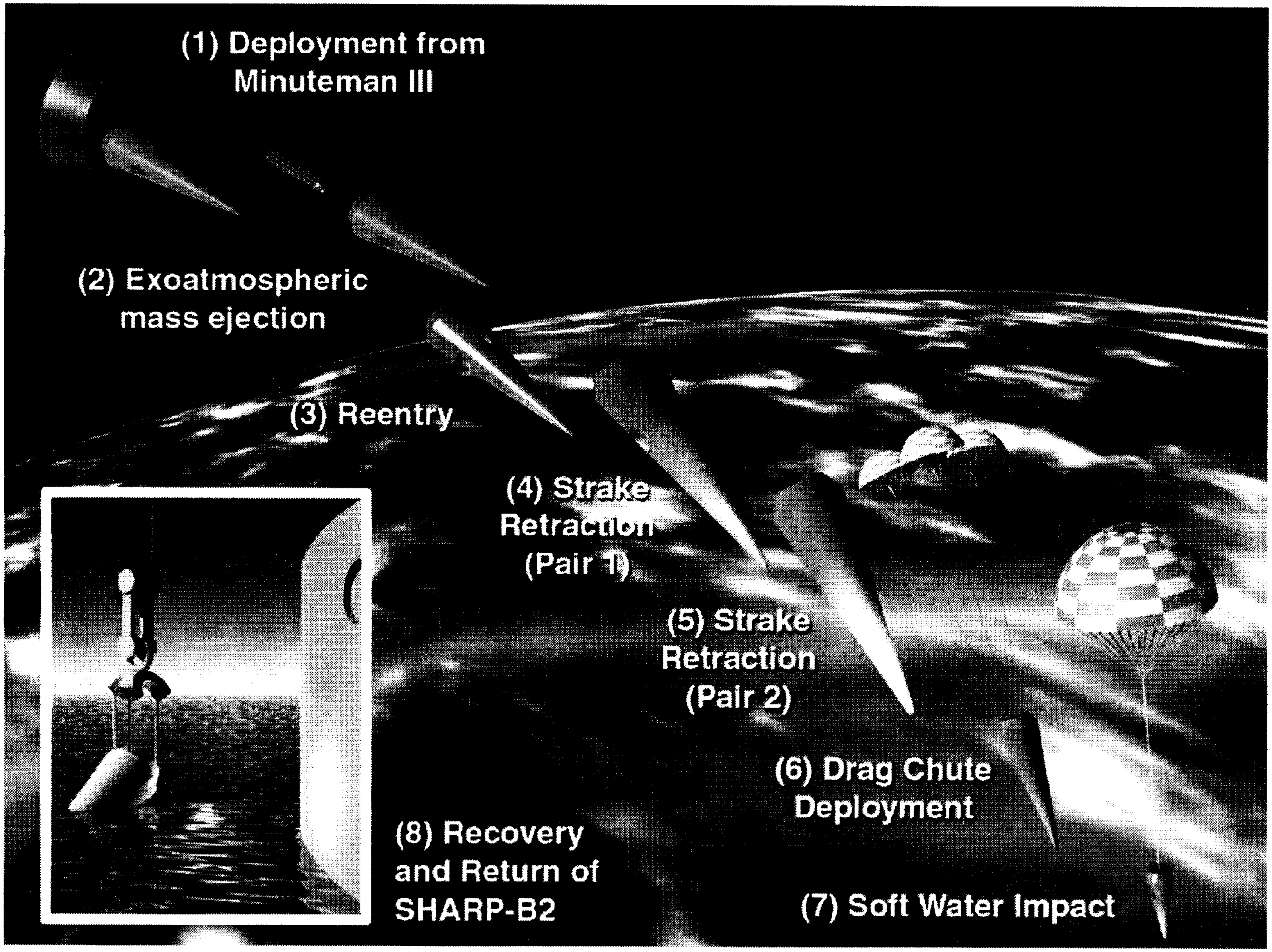


Other Flight Experiments (cont'd.)

- **Reduced Cost Small Payload Technologies**
  - Technology-- Technology -- Will demonstrate a small, generic, cheap, robust spacecraft kernal to manage power, attitude control, command, data handling, and communications. Eliminates need to design and build unique spacecraft components, reducing cost.
  - Description -- "Bitsy" is integrated from qualified subsystems (developed under contract to USAF). Will fly as a free-flyer, Hitchhiker Payload.
  - Team Members
    - Industry: AeroAstro
    - NASA: MSFC (Lead)

- **Ceramics for Sharp Leading Edges**
  - Technology-- Technology -- Sharp, passive, Ultra High Temperature Ceramic (UHTC) leading edge in relevant entry environments.
  - Description -- A modified MK123A re-entry vehicle with four sharp leading edges, retractable strakes (0.039" radius) made of UHTC. To be flown on Minuteman III launch vehicle and recovered (water recovery).
  - Team Members
    - Industry: Sandia, U.S. Air Force
    - NASA: ARC (Lead)

Slender Hypervelocity Aerothermodynamic Research Probe 2nd Ballistic Flight (SHARP B2)

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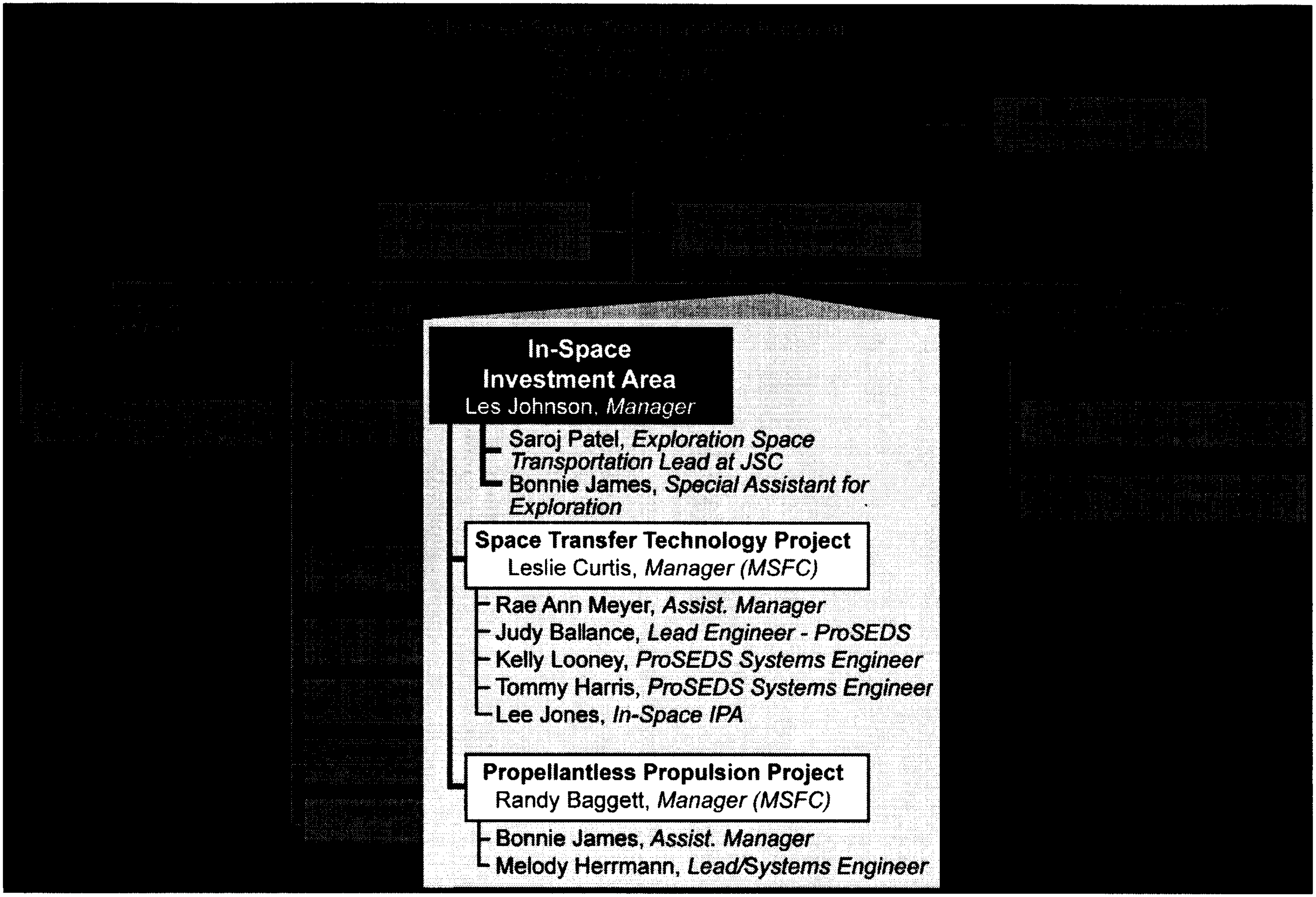

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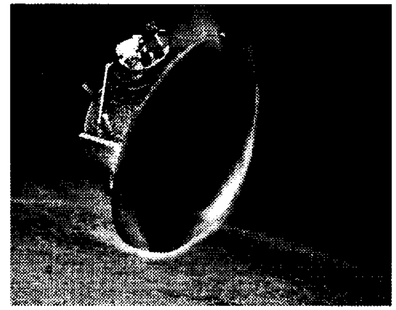
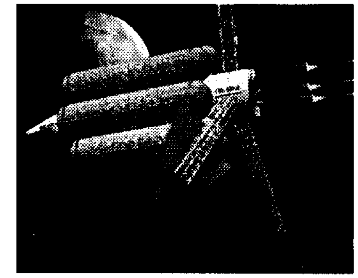
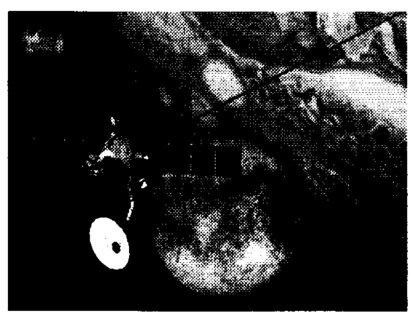
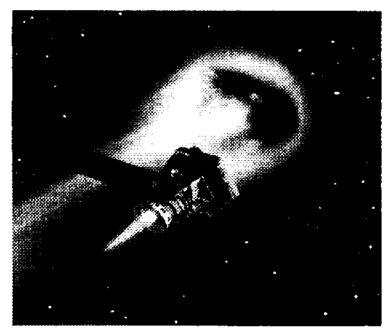
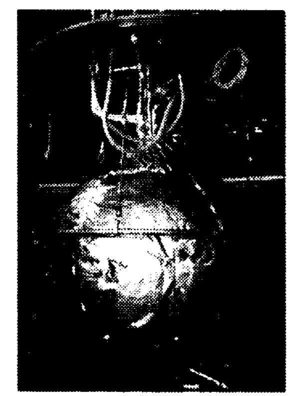
ASTP Organization

- Achieve within 15 years a factor of 10 reduction in the cost of Earth orbital transportation and a factor of 2 to 3 reduction in propulsion system mass and travel time required for planetary missions. Within 25 years enable bold new missions to the edge of the solar system and beyond by reducing travel times by 1 to 2 orders of magnitude.

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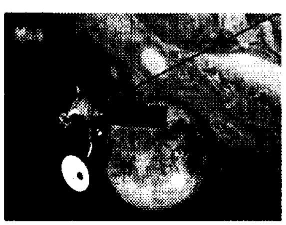
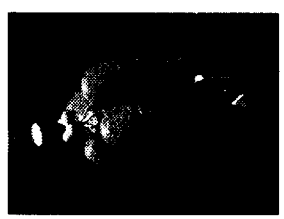
In-Space Transportation Goals

- High percentage of projected launches to Low-earth Orbit (LEO) will require upper stages.
  - More than 70% go to Geosynchronous Orbit (GEO) or higher.
- Under current total mission cost caps, more ambitious science missions require improvements in propulsion technologies.
  - DS-1 enabled by NSTAR solar electric ion propulsion.
  - Future planned missions require 2 to 3 times more Delta V.
  - Rendezvous and return missions will require similar investments in chemical propulsion systems and aerocapture technologies.
- Per current studies, human exploration missions to Mars, in-space transportation costs are projected to be higher than earth-to-orbit costs.
  - Affordable in-space transportation is enabling for human exploration missions (lighter weight systems, shorter trip time).
  - In-situ propellants offer significant potential to reduce mission costs.
- New opportunities to explore beyond the outer planets will require unparalleled technology advancement and invention.

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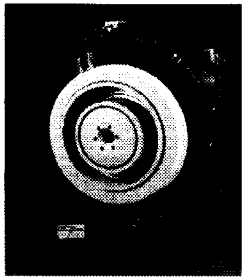
In-Space Investment Rationale

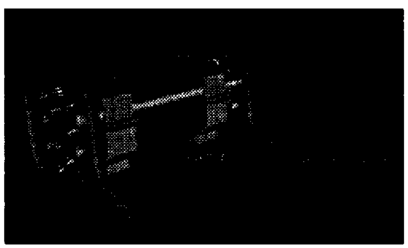


Electric Propulsion

Advance EP systems to reduce mass & cost of orbital transfer and to enable interplanetary missions

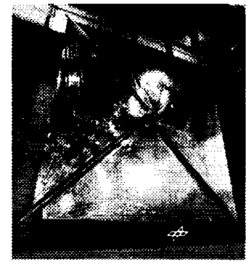
Cryogenic Fluid Management

Advance CFM systems to enable long term storage of cryogens in space



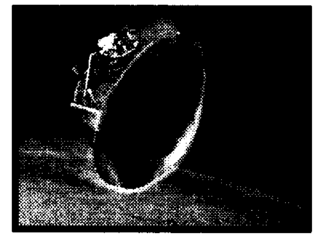
Fission

Develop fission technology to enable rapid, affordable access to any point in the solar system



Sails

Solar and magnetic sails to enable exciting new mission concepts and by reducing mass and overall trip time for interplanetary missions.

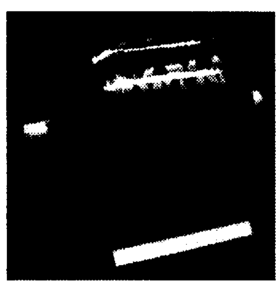


Aeroassist

Utilize aerocapture and aeroassist transportation systems to significantly reduce mass -- by using planetary environments for orbit capture and deceleration

Tethers

Develop reusable electrodynamic and momentum transfer tethers to reduce transportation system mass and cost



Light Weight Components

Develop light weight components to reduce the dry mass of spacecraft propulsion systems

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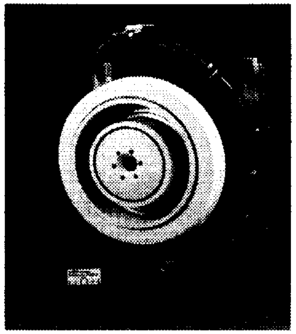
In-Space Transportation Technology Elements



Electric Propulsion

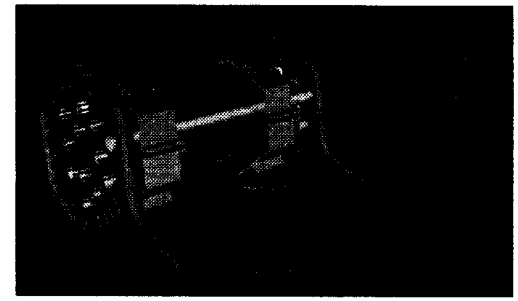
Advance EP systems to reduce mass & cost of orbital transfer and Enable interplanetary missions

- GRC – Hall, Ion, MPD, PIT technologies
- JPL – MPD (lithium), DS-1 tests, ion optics
- JSC – VASIMR Technologies
- MSFC- PIT (switch and ckt design)

Fission

Develop Fission Technology to enable rapid, Affordable access to any point in the solar system

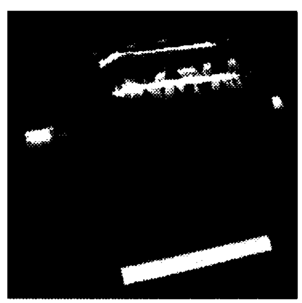
- GRC – Energy Conversion, Fuels, LANTR
- JSC – Two phase systems and technologies
- KSC – Operational and range requirements
- MSFC – Fuels, SAFE, System studies, non nuclear testing



Cryogenic Fluid Management

Advance CFM systems to enable long term Storage of cryogens in space

- ARC- Cryocooler & Refrigerator development, insulation
- GRC- Subscale/Component test, analytical modeling
- JPL - technology requirements
- JSC - In-situ propellant production
- KSC - GSE, quick-disconnects, insulation
- MSFC- System/Large scale test, analytical modeling



Light Weight Components

Develop light weight components to reduce the dry mass of spacecraft propulsion systems

- Center Roles are still being established

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Space Transfer Technology Project Elements

Propellantless Propulsion Technology Project Elements

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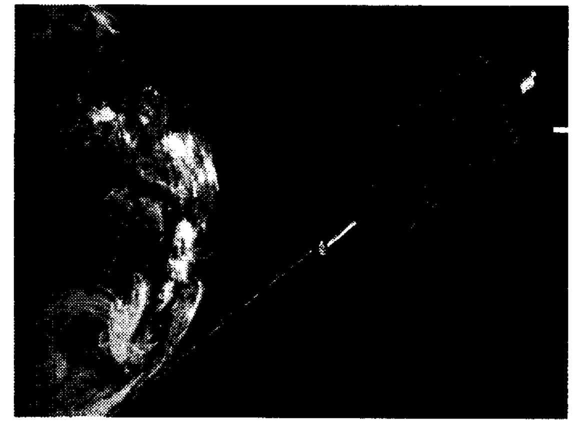
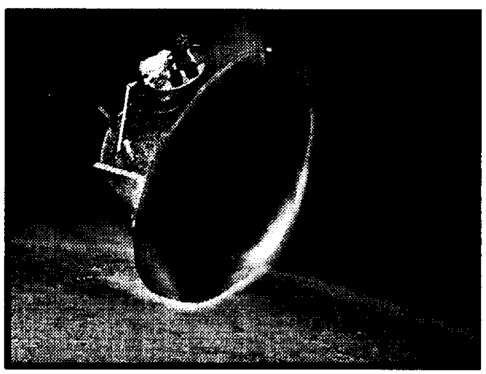
- Sails
  - Solar
  - Magnetic
- Center Roles:
  - JPL: TWG lead; system design; GN&C; Mechanical systems; Large structures; I&T
  - LaRC: materials & Lt. weight structures; mechanical system
  - MSFC: Prop. Physics;M2P2; mt'l & light weight structures
  - JSC: Large Structure environ.



- Tethers
  - Electrodynamics
  - Momentum Transfer Tethers
- Center Roles:
  - MSFC: TWG Lead; system design/performance; integrated test; tether survivability; deployer; GN&C; deployment test facilities; orbital tracking & collision avoidance
  - JSC: orbital tracking & collision avoidance



- Aeroassist
- Center Roles:
  - LaRC: TWG Lead; system design/performance; Aero/ Aerothermal analysis; structures; GN&C simulations
  - ARC,JSC,JPL,LaRC,MSFC: Vehicle design/system analysis
  - ARC: TPS; TPS Aerothermal sensors; Aerothermal analysis
  - JSC: GN&C; deceleration systems; Adv.. TPS materials
  - MSFC: Environmental models